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THE DESIGN OF ROCKET MOTORS

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1. Introduction

During this session we have, as usual, been listening to lectures on the methods and implications of space-travel. Most of these lectures have been, quite rightly, about the future. One of the functions of the B.I.S. is to act as a clearing house for ideas about the future of astronautics. Only once have we touched the present, and that was in Mr. Cleaver's talk on December 11, 1948, when, after discussing the ultimate performances of chemical rocket motors he reminded us that the best obtainable specific impulses to-day are little over 200 secs. This is certainly a sobering fact to a keen astronaut and yet, as we know from the performances of the W.A.C. Corporal and Aerobee in America, and the Vickers Transonic aircraft in this country, the present-day, astronautically-speaking, low performance rockets are certainly very useful pieces of equipment.

Most of our members must, I am sure, be conversant with the main types of rocket motor and their operation, and a large number also with the detailed mechanisms of specific types. But I feel that comparatively few would know how and where to start if asked to design a rocket motor with a given thrust and duration for a given application. It was with this in mind that I wrote this paper. Rocketry is still in its infancy and consequently different groups and individuals have to a large extent their own ideas on design. As in all branches of engineering, a good design depends to a great extent on "looking right" on the drawing board, but this is purely a matter of experience and is not easily analysed. Most of the other important items of design I hope to cover this evening, more or less in the order in which they are considered in an actual design.

It is always difficult in talking to a mixed audience to know where to start. Since rocket design is a highly technical matter I have tried to aim for the middle strata, technically speaking, of our Society. That is, I have endeavoured to pitch it at a technical level best suited to our technical and scientific members who are not rocket specialists and also those who, though not professional engineers or scientists have followed some, at least, of the technical literature on rockets of the past few years. I hope that any professional rocketeers may perhaps find some new aspect of rocketry touched upon, or at least that

they will find something to criticise or discuss. I also hope that non-technical members will be able to gather an outline of the process of rocket design.

2. Propellants (Refs. 7, 11, 20, 25, 29, 30, 31, 35.)

The first job in designing a rocket motor is to decide on the propellants to use. Although the huge list of "possibles" can be easily cut down to a fairly short list of "probables" the choice is still a difficult one. Starting with the full list and assuming that only those propellants that are a practical proposition to-day are to be considered then all of the high specific impulse propellants involving ozone, fluorine, fluorine oxide and the like, as oxidants, and liquid hydrogen, the light metals and boron hydrides as fuel, can be crossed out. We are left with liquid oxygen, nitric acid and hydrogen peroxide as oxidants, and a much longer list of fuels, chiefly alcohols, hydrocarbons and amines. None of the propellant combinations left have a specific impulse above about 250 sec. at a chamber pressure of about 20 atmos, and expansion ratio of 20 : 1. Thus on a question of performance there are many propellant mixtures giving about the same specific impulse (Fig. 1). If a high specific impulse is all-important then liquid oxygen is the choice of oxidant every time. Very often,

Oxidant	Fuel	S.I. Sec.	Temp. ° C.
Liquid Oxygen	Petrol	240	2980
Liquid Oxygen	Ethanol	240	2950
Liquid Oxygen	Liq. ammonia	255	2760
Liquid Oxygen	Hydrazine ..	265	2810
R.F.N.A. (15 per cent. N_2O_4) ..	Aniline ..	220	2760
R.F.N.A. (15 per cent. N_2O_4) ..	Orthotoluidine	220	2760
Mixed acid (90% R.F.N.A. + 10% H_2SO_4) ..	Aniline ..	210	2550
H_2O_2 (100 per cent.)	Hydrazine ..	250	2430
H_2O_2 (87 per cent.)	Methanol ..	225	2470
H_2O_2 (87 per cent.)	Nitromethane ..	225	2550

FIG. 1. Table of Propellant Combinations.

however, other factors are more important and a great deal of consideration of these factors is needed. Usually the most important design requirement, having once decided on the approximate specific impulse, is the combustion temperature. Generally speaking, with a given fuel, with the same specific impulse, liquid oxygen gives the highest temperature, hydrogen peroxide the lowest, and nitric acid in between. This gives one very good reason for preferring peroxide for medium specific impulses; but other matters must be taken into account before a final choice is made. Perhaps the next generally important technical point is that of overall propellant density. It will be as well

here to spend a few moments explaining the reason for its importance. The consumption figure for a rocket motor of specific impulse 220 sec. is about 16·0 lb/lb. thrust/hr. compared with the turbojet figure of 1·1 lb./lb. thrust/hr. With space at a premium as in an aircraft or missile it is, with this enormous consumption, essential to use the space economically. Thus as high a propellant density as possible must be used in order to get the greatest weight in a given space. Typical figures for the percentage by weight of propellant carried of gross loaded weight are 49 per cent. for the Me.163B and 69 per cent. for the V.2.

As the oxidant is always present in much greater quantities than the fuel its density is most important. In the Table (Fig. 2) it can be seen that the densities differ sufficiently for them to be important—liquid oxygen with the

	Liquid Oxygen	R.F.N.A.	H_2O_2 (80 per cent.)
Specific gravity, grm./c.c.	1·14	1·52	1·34
Freezing point, ° C.	− 219	− 46	− 22·2
Boiling point, ° C.	− 183	62	∼ 140
Per cent. available O_2, wt.	100	—	37·6
Viscosity, poise	0·0019	0·010	0·013
Coeff. of vol. exp., c.c./litre/° C.	—	1·2	1·0
Specific heat, cal./grm./° C.	0·395	0·5	0 63
Surface tension, dynes/cm.	13·2	42·3	75·3
Vapour pressure, mm. hg.	760	129	3·3

FIG. 2. Table of Properties of Oxidants.

highest specific impulse, has the lowest density, whereas nitric acid, with the next highest specific impulse has the highest density and hydrogen peroxide comes in between. The facts so far considered point to nitric acid as being a good all-round oxidant. For each specific application, however, various other technical factors must be taken into account. The most important of these are—

(i) Low vapour pressure, to ensure low losses and ease of pumping.

(ii) Stability to low temperatures; this is normally required to about −50° C. as most rockets are designed for high altitude operation.

(iii) Flat viscosity-temperature curve, to ensure steady required pump h.p. In particular temperature-viscosity curves as similar as possible for fuel and oxidant to ensure constant mixture ratio.

(iv) For hypergolic propellants an ignition delay of less than 0·1 sec. at all temperatures at which ignition is required.

So far I have considered only those properties directly affecting the performance of the rocket motor, in fact those that one would consider if producing a rocket for purely scientific interest with no thought of cost or handling difficulties. I have done this to keep the technical points together and because the questions of cost and handling depend to a great extent on the particular application of the rocket motor. For example, in military applications, cost is often a subordinate matter whereas the propellants must be safe and fairly easy to handle. For civil applications, as in assisted take-off work, besides being safe and easy to handle, the propellants must be cheap enough to make their use an economic proposition. And again, in certain instances of pure research, neither cost nor handling difficulties are of paramount importance, especially when only a few firings are to be made. I will now consider these other aspects, namely, availability and cost, safety, storage and handling, and compatible materials of construction. I will deal with each of these topics separately and compare the three oxidants under each heading.

(i) *Price and Availability*

Liquid oxygen and nitric acid are the only two oxidants under consideration that have, up to the present, been produced on a commercial scale in this country in the concentrations required. Liquid oxygen itself is not used to any great extent in industry, but gaseous oxygen is. Gaseous oxygen has to be transported in heavy and cumbersome pressure bottles. In many cases where it is needed only at atmospheric pressure it has been found economic to transport the oxygen as liquid and vapourise it where it is required. For large-scale consumption the present price of liquid oxygen is about £24 per ton. One big drawback with liquid oxygen compared with the other two is that it boils at −183° C. Consequently, it has to be kept in insulated vessels and is continuously evaporating. The rates of evaporation depend on the type and size of vessel. For example, the rate of loss from a 60 lb. Dewar vessel is 2 per cent. per hour and from a 30,000-lb. storage tank only 0·1 per cent. per hour. But the greatest losses occur during transfer, chiefly due to the heat capacity of the tank into which liquid oxygen is being poured, and its lagging. In practice, the Germans found that the loss between manufacture and firing when used in the V.2 was about 50 per cent. This means that the real cost of liquid oxygen as fired, is about £48 per ton. Liquid oxygen has one possible advantage above the other two and that is that for some purposes it may be possible to manufacture it *in situ*. The normal Heylandt manufacturing plant is much too cumbersome to be made transportable but another method, due to Kapitza, utilises a high-speed turbine as the expansion plant. Thus it might be possible, particularly where projectiles are concerned, to manufacture liquid oxygen on the spot and thus cut down losses.

Concentrated nitric acid (98 per cent.) is regularly available commercially at a cost of £26–£28 per ton. Red fuming nitric acid (R.F.N.A.) which is normally used in rockets contains anything up to 20 per cent. N_2O_4, and in bulk costs a little more than concentrated nitric acid.

Hydrogen peroxide has not so far been available in this country at anything over 30 per cent. concentration. It was produced in Germany in large

quantities at 82–83 per cent. concentration and was the most widely used of all oxidants. Several methods of manufacture were in use in Germany, and by the end of the war about 16,000 tons (80–85 per cent.) were being produced annually at an average cost of £190 per ton.

(ii) *Safety*

It is the nature of things that a safe oxidant does not exist. But some are worse than others. Liquid oxygen is perhaps the most harmless of the three. It is non-toxic and if sprayed on to the body it evaporates quickly and does no harm, although immersion in the liquid will cause extremely severe frost-bite. The liquid itself or the gas from it are absorbed by porous materials which will then burn very fiercely or explode, if ignited. Again the ignition point of all materials is considerably lower in oxygen than in air. As liquid oxygen is continually evaporating the storage tanks have to be well ventilated to avoid accumulations of gaseous oxygen with the consequent dangers of fire and explosion. If a fire does occur with liquid oxygen, it is exceptionally severe, burning not only normally combustible materials but most metals also. In a projectile the risks occasioned by its accidentally crashing with still partially filled tanks are negligible, but they are of great importance with piloted aircraft. If an aircraft crashed then the danger of fire would be considerable and the fire, once started, uncontrollable. Care also has to be taken during storage and use that organic materials such as grease do not come into contact with it.

Neither nitric acid nor its vapour are poisonous, although by their corrosive action they are very dangerous to the tissues. On the skin, nitric causes severe burns unless washed off immediately and even a small amount in the eye can be very dangerous. Nitrogen peroxide as used in R.F.N.A. is extremely toxic having an action similar to that of carbon monoxide. Gas masks must be worn when handling all kinds of nitric acid and mixtures. Hydrogen peroxide also is non-toxic and forms white patches on the skin if washed off fairly quickly but causes skin peeling if left on longer. Again the vapour given off is harmless though irritating and peroxide in the eye is not dangerous if washed out quickly. Gas masks are not needed in its handling. Unlike a liquid oxygen fire, however, fires with these two oxidants can be controlled fairly readily by flooding with water. Although this indicates that these two will be, generally speaking, safer than liquid oxygen in case of a fire, it must be realised that a great deal also depends on the fuel. Hypergolic or self-igniting mixtures are possible with both nitric acid and peroxide and in the event of a crash, these mixtures would automatically burn or explode if the tanks burst. Also under certain conditions of detonation or rapid heating, high strength peroxide can be made to explode. Special precautions must be observed during the transfer of these two oxidants both for the above reasons and because either of them, when dropped on to certain kinds of organic matter, *e.g.* cotton waste, will cause a spontaneous conflagration. Thus special sealing arrangements for pumps and hose connections must be made and as an added precaution, a copious supply of water must be readily available. Nitric acid is especially difficult to handle due to its low surface tension, causing it to "creep" very rapidly over any surface once it is allowed to leak. (Although liquid

oxygen has a lower surface tension it evaporates and is not corrosive.) A particular danger attached to the use of peroxide is that of catalysation by contaminants. This can only be guarded against by stabilising the peroxide by means of small additions of such chemicals as phosphoric acid, tetrasodium pyrophosphate or 8-hydroxyquinoline. Even so, this stabilising must not be overdone, otherwise it makes ignition and combustion more difficult. The only real safeguard is a daily check on the peroxide temperature and a periodical check on its concentration. If a contaminant should by misfortune enter the tank, say by way of a vent, and start to decompose the peroxide this will be noted by the rise in temperature and the tank can be flooded before it becomes too dangerous. With nitric acid contamination has fewer possibilities of danger but is still important. Dilution with water either from the atmosphere or other means of accidental contamination may promote tank corrosion which, if not carefully watched for, may cause leakage. Contamination with organic matter or corrodible metals would cause evolution of gases.

(iii) *Storage and Handling*

Many points under this heading have already been dealt with, but there are several other items worth mentioning. Although the handling of all three oxidants requires trained personnel, liquid oxygen is the least unpleasant of them and the least dangerous. Only asbestos gloves are needed during its handling, while for the other two, complete outfits of special clothing are required. All three can be easily pumped, although it must be remembered that nitric acid creeps badly and thus needs more care than the other two, and liquid oxygen boils off very rapidly during transfer thus necessitating as few transfers as possible. Due to its stability it is possible to store nitric acid for long periods without deterioration in either storage or projectile tanks. Thus projectile rounds can be filled at the factory eliminating the need for further handling of the propellants. Peroxide, being less stable, can be stored for considerable periods in vented tanks with a slight fall-off in concentration (maximum of 2 per cent. per annum). This evolution of oxygen renders it impossible to store peroxide in a sealed tank. Liquid oxygen can be stored for short periods only and then with a comparatively high rate of loss, thus rocket motor tanks must be filled as soon as possible before firing.

(iv) *Materials of Construction*

I shall deal here only with materials that will come into contact with the oxidants. Materials for use with liquid oxygen are limited due to the fact that many materials are brittle at -183° C. Materials for tank and pipe-line construction with sufficient strength and ductility at this temperature include copper, brass, monel metal, aluminium alloys and austenitic steels. Wherever possible it is best to use copper or its alloys, as in case of fire these are less likely to burn than other metals. For storing small quantities, Dewar flasks, made of copper are commonly employed, but for large quantities or for pressure vessels austenitic steels are more common, with an outer insulating layer, usually of glass wool, magnesium carbonate or asbestos. For washers and gaskets, soft copper or aluminium can be used—all of the rubbers and synthetics are useless at this low temperature.

Nitric acid poses perhaps the most difficult of materials problems due to corrosion troubles—particularly R.F.N.A. Pure aluminium (99·5 per cent. and over) is the only possible material for long-term storage of concentrated nitric acid (95 per cent. and over) but stainless steels can be used for lower concentrations. Aluminium alloys are widely used for pipe-lines, valves, pumps, etc., where the contact is for a short time only, and also for tanks—especially for projectile use. Due to its tendency to creep, all types of bolted joints are avoided as far as possible, but where washers and seals are needed, there are only a few suitable materials, mostly plastics, including P.V.C. and polythene.

The main problem with peroxide is that of catalysis. The only suitable metal for storage tanks is pure aluminium (99·5 per cent. and over) although for short-term storage, aluminium alloys and stainless steels with specially treated surfaces are acceptable. Natural rubbers are all attacked and the only suitable packing materials are certain synthetics, again including P.V.C.

I have so far dealt only with oxidants and those at some length. This is for several reasons. As we have seen, there are many pros and cons for each of the three oxidants dealt with and in practical cases it is often very difficult to decide which to use—it is a case of trying to choose the least of three evils! The choice of a fuel is normally a much simpler matter, as most fuels do not possess such awkward properties and there are so many to choose from. As with oxidants, fuels should be chosen with a high density, suitable freezing point for the particular application and a flat viscosity/temperature curve. With a cooled motor using the fuel as the coolant, as is usually the case, further considerations must be taken into account. In the first place, the coefficient of heat transfer with a reasonable coolant velocity (30–60 ft./sec.) must be sufficiently high to conduct the heat away rapidly enough to keep the outer surface of the chamber at a lower temperature than the boiling point of the coolant. Secondly the heat capacity of the coolant must be high enough to absorb all of the transmitted heat without boiling. For these reasons it is found advisable with some fuels, *e.g.* methyl and ethyl alcohols, to add a certain amount of water to improve their qualities as coolants without greatly impairing their efficiency as fuels, *e.g.* V.2, which used a 75/25 mixture of ethyl alcohol and water. As with oxidants very often the dominant factors governing the choice are economic or logistic rather than performance ones. For example, with an A.T.O. or climb boost rocket for use with a turbine-driven aircraft, the fuel may be fixed as aviation kerosene in order to reduce the number of fluids to be handled on the aerodrome. Certain chemicals have the property of being self-igniting with nitric acid and peroxide, *e.g.* aniline with nitric acid and hydrazine hydrate with peroxide, thus doing away with the need for an ignition device. This point has to be borne in mind when choosing propellants, as it considerably simplifies the chamber design. It is often found that several propellant combinations vie with each other for the final choice, but when this is made it is possible to continue to the chamber design.

3. Combustion Chamber Design (Refs. 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 21, 22, 23, 25, 32, 33, 36.)

The first thing is to decide on the combustion chamber pressure to be used.

As can be seen from Fig. 3 the thermal efficiency falls off very rapidly for expansion ratios less than about 10 and rises very slowly for ratios above about 40. These figures can be taken as the practical limits and if the motor is expanding to 1 atmo. can be taken as the limiting chamber pressures. As the chamber pressure increases the chamber, piping, valve and pump weights

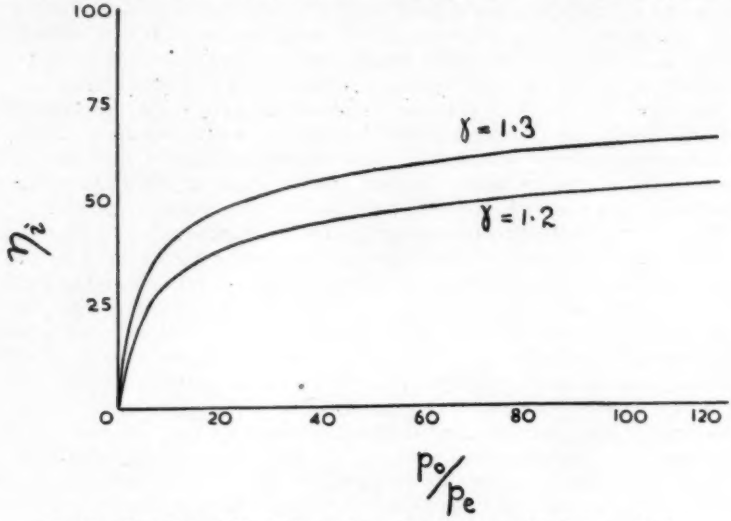


FIG. 3. Variation of Ideal Thermodynamic Efficiency with Pressure Ratio.

all increase, as also does the power required to inject the propellants. Although a saving in propellant weight is obtained by increasing the chamber pressure a point is reached where the extra equipment weight more than offsets this. At present this figure is of the order of 20 atmos. and most propellant calculations have been carried out at this pressure. However, this figure should not be accepted blindly as with improved materials and techniques this optimum pressure is always rising. For example, in the V.2, designed near the beginning of the war a pressure of 15½ atmos. was used, whereas in the 109–509 A.2, designed later, a pressure of 21 atmos. was employed. In cases where high performance is being particularly aimed for, it is sometimes advisable to carry out calculations for several different pressures in order to determine the optimum figure.

The next step is the calculation of the exact performance, temperatures and throat and exit areas. For low temperature propellants ($\leqslant$ 2,000° K.) the work involved is comparatively light, but for temperatures above this dissociation has to be taken into account and the work is very tedious. A description of the various methods of calculation would need a paper to itself. As they are really the work of physical chemists and are not easily condensed to give an intelligible picture I intend to miss them completely and give only the results.

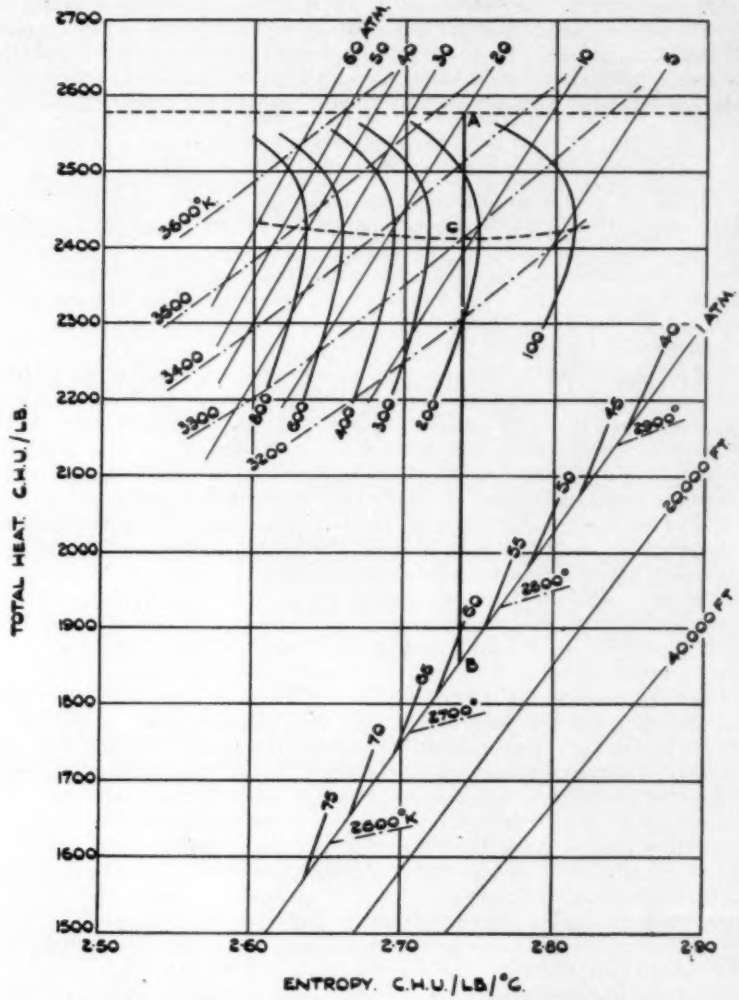


FIG. 4. I — ϕ Diagram for Liquid Oxygen/Petrol Combustion Products (3 to 1 Mixture Ratio).

A typical I — ϕ diagram is shown in Fig. 4. It is a little more complicated than the normal I — ϕ diagram as curves of constant specific mass flow are also included in order to determine throat and exit areas. Also from this diagram can be obtained specific impulses and combustion temperatures over a

range of pressures. An example of its use is as follows. Suppose figures for specific impulse, and throat and exit areas are required for an expansion from 20 atmos. to 1 atmos. From the point A, where the total heat line crosses the 20 atmos. isobaric, a vertical line is dropped to cut the 1 atmos. isobaric at B. This line represents an isentropic expansion. The specific impulse is given by:–

$$\text{S.I.} = \sqrt{\frac{2\text{J}.\Delta\text{I}}{g}}$$

where ΔI is the drop in total heat represented by the line AB. In this case ΔI = 725 C.H.U./lb. and the specific impulse = 253 sec. The point C on the line where it crosses the line of maximum specific mass flow represents the throat area, which in this case is about 230 lb./ft.²/sec., or in other terms, 2·5 in.²/1,000 lb. thrust. The mass flow line at B represents the exit area which here is 9·8 in.²/1,000 lb. thrust. The relevant temperatures are obtained from the isothermals.

Most rocket motors, however, are not intended for operation at ground-level and the calculations are therefore slightly more complex than just indicated. Taking the fairly simple case of a motor intended for operation at a given fixed altitude the specific impulse and outlet area can be determined in a similar manner to the above by adding isobaric lines to the I $-$ ϕ diagram for pressures less than 1 atmos and extending the isentropic line down until the required atmospheric conditions are reached. The specific mass flow lines are also extended and thus the theoretical exit area for complete expansion is obtained. There is though a practical limit to the exit diameter. The diameter can be increased until one of two things happens. (1) The increase in area is so great as to bring about heat transfer difficulties, (2) the nozzle becomes so large that the drag offsets the gain in performance. When a chamber is not used at its design altitude there is, besides the thrust derived from the rate of change of momentum of the exhaust gases, a component due to the difference between the nozzle exit pressure and the ambient pressure. This is an increase if the exit pressure is higher than the ambient pressure and a decrease if the exit pressure is lower than the ambient pressure. In a high percentage of cases the rocket motor has to function over a wide range of altitude conditions. For aircraft applications this is from sea-level to 40,000 ft. or 50,000 ft. and for projectiles such as the V.2 up to 100,000 ft. Under these conditions an exit area corresponding to somewhere between the two extreme operating conditions must be chosen as the design condition. The design altitude for the V.2 and 109–509 C cruising chamber were 8,000 ft. and 30,000 ft. respectively.

So far we have fixed only on two dimensions, the throat and exit diameters. The rest of the geometry of the nozzle and chamber has still to be determined. One of the largest sources of loss is in the nozzle, particularly in the divergent portion. Wall friction is one of the causes so that this would be reduced by keeping the nozzle as short as possible, that is, using a large divergence angle. Unfortunately, this leads to radial momentum losses and in extreme cases to breakaway from the wall. Both theory and practice show an optimum angle of about 15° with a thrust loss of around 3½ per cent. This sometimes causes heat transfer problems due to the large area of the divergence, and the

angle can be increased to 30° with a corresponding thrust loss of 5 per cent. The only requirement for the convergence is that it should be smooth with an angle not greater than 60°.

In dealing with the nozzle it was assumed that the gases entering it were completely reacted thus allowing an isentropic expansion. It is now necessary to examine the phenomena in the chamber in order to determine the volume and shape requirements. The combustion process can be broken down into several phases; the mechanical preparation and atomisation of the propellants by spraying; mixing of the propellants; preheating up to the ignition temperature; and reaction. These processes overlap according to the construction employed. For example, mechanical atomisation can be accompanied by mixing and heating and even by partial reaction. The space required for atomisation and mixing depends on the type of injector, the pressure differential across it and the chamber pressure. Heating of the propellants in a practical chamber starts at the injector; this heating is partly by radiation but chiefly by direct thermal conduction. The rapidity of heating is naturally dependent on the combustion temperature. These three processes in a rocket with a well-designed injector system take up the smaller part of the chamber volume, the larger part being taken up by the reaction itself. The reaction zone can be conveniently divided into two parts, the flame front, or main reaction zone and the rest of the chamber where the reaction is completed and equilibrium attained. All of these processes are, of course, interlinked and it is difficult to separate them for the purpose of obtaining design data. In practice we are only interested in providing sufficient chamber space for all of these processes to be carried out efficiently. Thus the following arguments and methods are used. Since each of the processes in the chamber needs a certain time the chamber must be of such a size as to allow the propellants to stay in the chamber for the sum total of these separate times. This total time is known as the "time of stay." The direct measurement of this time is very difficult and so it is necessary to find some easily measurable property of the combustion chamber which can be approximately related to this time. We have already seen that the propellants are, for the greater part of the chamber space, in the gaseous state. Thus as a first approximation we can consider the chamber as being filled with the products of combustion at the flame temperature. It is obvious that with a given gas composition at a given temperature the time of stay will be directly proportional to the chamber volume and inversely proportional to the throat area, *i.e.*:—

$$t = k\frac{V}{a} = kL^*$$

This ratio of chamber volume to throat area is known as the characteristic length and is perhaps the most important value in chamber design. Given a good injector system and chamber design the L^* is effectively varied only when different propellants are used. Thus from a practical point of view when the minimum L^* for a given propellant mixture has been found by experiment, this can be safely used as a basis for a new design. In many cases, however, when a new design is being tested several tests are made with different length

chambers in order to find the minimum allowable size, thus cutting down the weight and area for heat transfer as far as possible. Fig. 5 shows the variation of specific impulse with L* for a series of tests conducted in Germany with oxygen and diesel oil. It can be seen that a maximum specific impulse of 265 sec. is obtained at an L* of 83 in. The chamber shape is usually cylindrical, or nearly so, for ease of manufacture. Tests have also been carried out on the

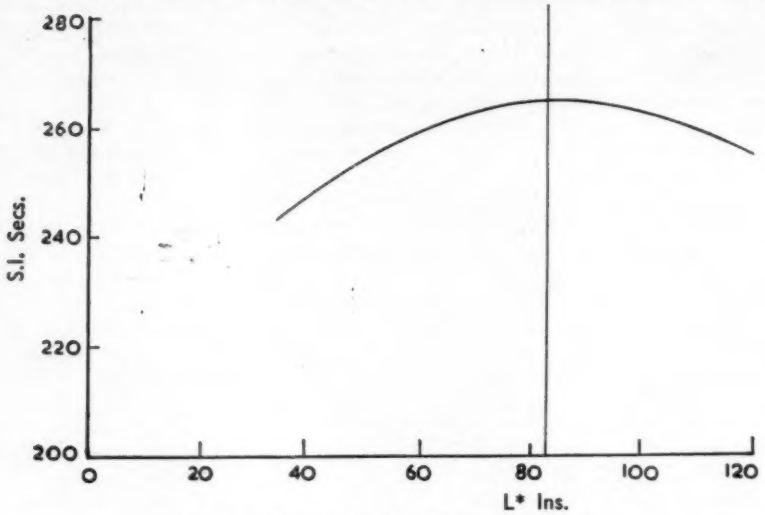
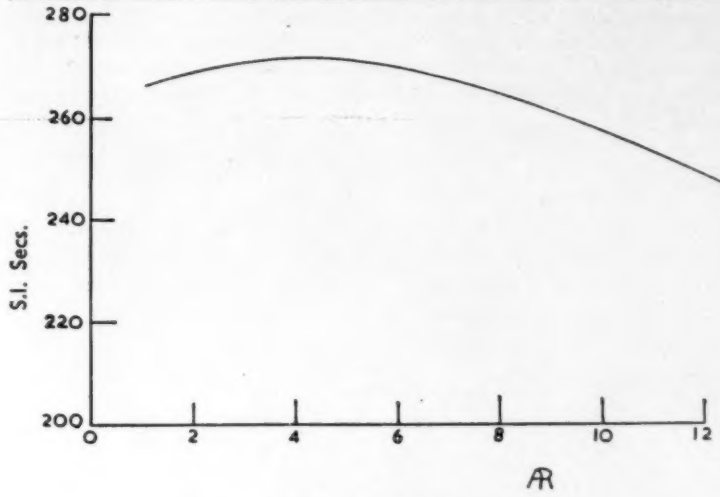


FIG. 5. S.I. *v.* L* for Oxygen and Diesel Oil.

effect of the length/diameter or aspect ratio on the specific impulse for a cylindrical chamber, also using oxygen and diesel oil. The results are shown in Fig. 6 and it can be seen that the curve is at a maximum between 1 and 6. Later work has shown that from both performance and heat transfer points of view a value of about 1–2 is an optimum for most propellants. I have used these figures as an illustration as they are about the only readily available ones, but I should point out that they were determined for rather unusual chamber conditions. In the first place the chamber pressure was 40 atmos, twice the usual value, the injection differential pressure of the oil was 100 atmos, about ten times the usual maximum and the oxygen was injected as a gas at about 400 ft./sec., instead of as a liquid as in a practical motor. Finally, water cooling was used and in the very long chambers used for obtaining high L* values the heat lost in cooling was sufficient to lower the motor performance as can be seen in Fig. 5 where the specific impulse falls off with L* figures above 83 in. In a regeneratively cooled motor this heat is returned and above the critical L* value the specific impulse remains sensibly constant.

The next step, having decided on the approximate chamber dimensions, is to determine the material of construction and the necessary thickness. The



S.I. v. AR. FOR OXYGEN & DIESEL OIL

FIG. 6

following conditions must be fulfilled. (1) The chamber must be strong enough to withstand the stresses due to the differential pressure across the chamber and due to thermal gradients, (2) the temperature of the gas face of the wall must be lower than the melting point of the material, (3) the total amount of heat transferred must not be sufficient to bring the coolant to either its boiling point or the temperature at which it decomposes, (4) the temperature at the outer surface of the chamber must be below the boiling point or decompoisition point of the coolant, to eliminate surface bubbles which would interfere with the heat transfer. Thus the choice of a material depends as much on the heat transfer properties as on the strength properties of the material at high temperatures. The calculation of the heat transfer and the temperatures across the walls of a rocket chamber is one of the most unreliable processes in rocket design. This is because neither the theory for supersonic heat transfer nor the necessary properties of gases at high temperatures are known. For any calculations that have to be made the subsonic theory for convective heat transfer has to be used, *i.e.*:—

$$\frac{hd}{k} = 0{\cdot}023 \left(\frac{vd}{\nu}\right)^{0{\cdot}8} \left(\frac{C_p \mu}{k}\right)^{0{\cdot}4}$$

where h = coefficient of heat transfer.
d = mean hydraulic diameter,
k = thermal conducivity,
C_p = specific heat at constant pressure,
μ = absolute viscosity,
ν = kinematic viscosity.
v = gas velocity.

The viscosities and conductivities of the gas mixtures are not known above temperatures of a few hundred ° C. and existing equations for them have to be extrapolated well outside the normal range—a very risky procedure. This equation is also applicable to the coolant side. For the conduction through the wall

$$h_w = \frac{k}{L}$$

where k = thermal conductivity,
L = wall thickness.

Now the heat transmitted from the gas, through the wall, and to the coolant is the same amount and if we let the temperatures be denoted as follows:—

T_1 = body of gas,
T_2 = inner surface of wall,
T_3 = outer surface of wall,
T_4 = body of coolant,

then

$$h_g\,(T_1-T_2) = \frac{k}{L}\,(T_2-T_3) = h_L\,(T_3-T_4).$$

Thus starting at the coolant entry and using a step by step process the temperatures and heat transfer can be obtained all the way along the chamber. Unfortunately due to the uncertainties of the theory and the physical properties mentioned earlier, the error involved cannot be stated; the value of the results so obtained are therefore limited. Their greatest use is when experimental and theoretical values exist for another chamber using the same propellants, thus giving an indication of the probable error. Even if this comparison does not exist the calculations can be very useful for comparing the effect of various materials, combustion temperatures and coolant velocities where relative figures only are required. The very high heat flux obtaining in the chamber wall makes the thermal conductivity of the material extremely important. It seems that a straight carbon steel because of its higher conductivity is often more suitable than an alloy steel, although its tensile properties at high temperatures may be much inferior. In some instances it is found that even an aluminium alloy is better than a steel. In some cases where the limit of regenerative cooling is reached or where for some other reason it is not possible to keep the wall temperature low enough, film cooling can be used. This consists of a ring of holes just forward of the section to be cooled with the coolant injected through them at a few lb./in.^{2} above the local chamber pressure. The coolant spreads itself in a film over the wall thus lowering the wall temperature.

All that now remains of the chamber to be designed is the injector system. As mentioned earlier the function of the injector system is to atomise and mix the propellants as intimately as possible to ensure rapid combustion. Basically there are two methods in use for producing small droplets. The first of these is by causing the propellant streams to impinge either on each other or on a target plate, the degree of atomisation being dependent chiefly on the velocity of impact and consequently on the differential injection pressure. The second

method consists of producing very thin films or jets of the propellants which are then broken up into small particles by friction with the surrounding medium. The shape of the outlet and density of the surrounding medium are important in deciding the degree of atomisation and depth of penetration. The higher the back pressure and the higher the pressure differential across the injector the smaller are the sprayed drops and the more quickly are they heated and evaporated. Two ways of obtaining a thin film are used, the best known perhaps being the swirl jet. Here the liquid flows tangentially into a nozzle chamber and on ejection forms a thin rotating cone. The larger the amount of energy of the rotating ring in the nozzle chamber the thinner the cone and the smaller the drops. The other way of producing a thin film is to spray the propellants through narrow annular rings, alternately oxidant and fuel. These rings are made to impinge on each other so this is really a combination of the thin film and impinging jets. There has been much written on discharge coefficients and spray patterns of injectors and most types seem capable of successful development for any propellant combination, so I do not intend to say any more on the matter.

The last item to be considered is that of ignition. The problem occurs only with non-self-igniting propellants and can be solved in one of several ways. Perhaps the most common is that of introducing a flame either from outside the motor as in the case of the V.2 which used a catherine wheel device ignited beneath the rocket, or from a small built-in ignition chamber. For one-shot motors a solid propellant such as cordite can be used to fill this, but for multiple starts a subsidiary controllable propellant supply must be used. A further method is to inject self-igniting propellants into the main chamber first and then the main propellants.

4. Propellant Supply Systems (Refs. 1, 15, 16, 37, 38.)

Under this heading comes most of the rest of the rocket motor—tanks, pressuring system, pipes and valves. In most other heat engines the fuel flow is so low that the fuel supply systems are very small and light compared with the rest of the engine. In rockets the propellant flow rate is so high that the supply system occupies a high percentage of the total weight of the unit and so great efforts must be made to keep the supply system as light as possible. The curves in Fig. 7 are useful in giving a general indication of the type of supply system to use in order to obtain the maximum effective specific impulses. The definition of effective specific impulse is:—

$$\text{S.I. effective} = \frac{\text{Thrust} \times \text{Time}}{\text{Propellant weight} + \text{Dry engine weight.}}$$

From these curves it appears that the liquid-propellant rocket comes into its own for durations of 5 sec. and above. The pressurised tank system holds its own from 5 to 25 sec. and for longer periods the turbo-pump system is the best. These figures are based chiefly on designs of the later war years and so may be considered slightly pessimistic to-day; but all the same they do give a useful indication of expected effective specific impulses. It will be seen that as the running time increases the effective specific impulse approaches a value of about

200 sec. This is to be expected as with longer running times the ratio of propellant weight to engine weight becomes greater and the effective specific impulse approaches the specific impulse. Sufficient information does not exist for pressurisation by generated gas to be able to give a curve for its range of application. Its most probable range lies somewhere between 10 and 40 sec.

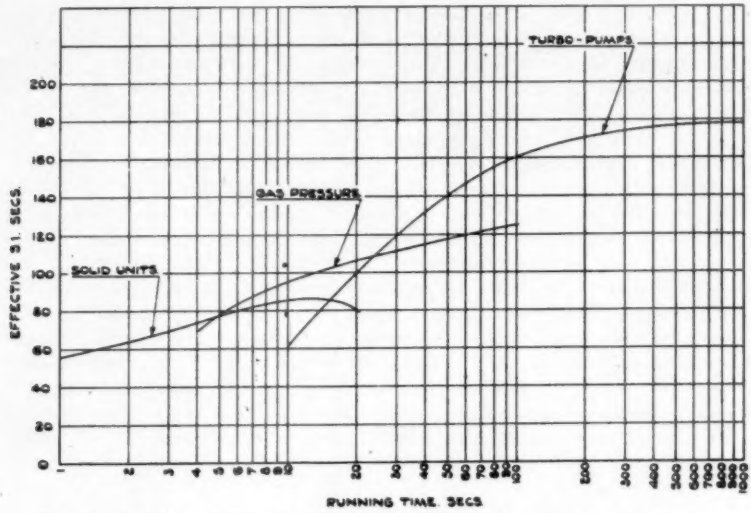


FIG. 7. Variation of Effective Specific Impulse with Running Time for Various Types of Unit.

Although these curves are very useful for a preliminary analysis, each unit must be designed on its own merits. The greatest factor against the use of a turbo-pump system is that of cost; this is particularly the case with projectiles, where it may be necessary, in order to keep the cost down, to use a pressurised tank system, even though a turbo-pump system would give a higher effective specific impulse.

(i) *Propellant Tanks*

There are two different types of propellant tanks—low-pressure tanks for pump-feed and high-pressure for gas-feed. The low-pressure tanks present comparatively few problems, they need only withstand a pressure sufficient to eliminate pump cavitation. This certainly will not exceed 50 lb./in.^{2} and is usually much lower. This means they can be very thin and often the problem is not that of the pressure involved but that of tank stability. Care has to be taken that the tank can withstand any lateral accelerations that may be imposed during swift manœuvres and external pressure loads due to rapid descent through the atmosphere. One great advantage of the low-pressure tank is that it can be made to conform to the contours of the aircraft or projectile it is to

fit into, thus using space advantageously. This is of particular interest in aircraft propulsion where slab-tanks fitting in the wings can be used. The design of high-pressure tanks for use from 300 to 600 lb./in.^{2} is much more difficult as they may constitute up to 75 per cent. of the dry weight of the rocket engine and consequently their weight must be reduced to a minimum. The lightest form of pressure tank for a given weight of propellant is a sphere, but as this is uneconomical of space a cylindrical form with dished ends is commonly employed. In order to save weight, especially in projectiles, the tank can be made to form the outer skin of the projectile and then has to be stressed to take the thrust of the motor and air loads as well as the internal pressure. Because of the low weight requirements the use of materials with high strength properties is essential. Small tanks can be satisfactorily heat-treated but with large tanks adequate and uniform heat-treated properties cannot easily be obtained. This immediately limits the choice of materials for large tanks. With fuels hardly any corrosion troubles occur, but with oxidants, as has been seen earlier, this is a major consideration. Generally speaking corrosion-resistant stainless steels are used for nitric acid and a 5–8 per cent. magnesium alloy for peroxide and liquid oxygen—or an austenitic steel for the latter. As reduction of weight is of such great importance it is essential that the last drop of each propellant should be ejected from the tanks. In a projectile with constant acceleration in one direction only this is a fairly simple matter as the propellants stay at one end of the tanks and a straightforward pipe placed at the correct end will automatically collect all of the propellant. In many applications high accelerations in all directions must be allowed for, and methods for collecting the fluid from all parts of the tank have to be devised. One common method of expelling the propellants in pressurised systems is by means of a piston, and this ensures the ejection of all of the propellant no matter what accelerations are imposed. A modification of this is to use a diaphragm clamped at the centre of the tank with the fluid at one side. When the tank is pressurised at the opposite side of the diaphragm, the diaphragm acts as a piston. When no piston is used and the accelerations are expected to keep the fluid pretty well to one end then a swinging pipe system can be used. When accelerations in all directions are expected the fluid can be contained in a suitable flexible bag in the tank attached to the outlet pipe; when the tank is pressurised the propellant is forced out of the bag. Alternatively the propellant can be outside the bag and the bag inflated.

(ii) *Gas Pressurising*

The gas most commonly used is nitrogen as it is inert. In America helium is sometimes used where there is great need to save weight, but it is much more expensive. The gas is stored at pressures between 2,000 and 5,000 lb./in.^{2}, depending on the compressing equipment available, and the vessels are usually cylindrical with hemispherical ends made of high tensile alloy steel. The gas is passed first through a stop valve, then through a reducing valve to the propellant tanks. The function of the reducing valve is extremely important as often it is the only piece of equipment controlling the propellant injection pressure which, in turn, controls the thrust of the motor. With most motors

of the simple gas pressure, uncontrolled type, a fairly constant thrust is needed and so it is imperative that the reducing valve should give a fairly constant pressure to the tanks during the run.

Where generated gases are used for pressurising they are generally produced from cordite or one of the plastic propellants. Comparatively little data exists on this method although it has been used successfully on a number of occasions. Where a piston type tank is being used the gases can be used directly, relying on the expansion to cool them sufficiently and the piston to act as a good enough heat barrier to prevent any damage to the propellants. With any other method of expulsion it is usual to cool the gases before they enter the tanks by injecting water.

(iii) *Turbo-Pumps*

The design of a turbo-pump is an art to itself. Much has been written about both turbines and pumps and I intend to mention only a few of the rocket aspects of their design. Generally speaking high-speed single or two-stage impulse turbines coupled to centrifugal pumps are used. Again as we have seen before the chief problem to be faced is that of deciding on a compromise between efficiency, weight and cost. In order to gain high efficiencies, and consequently low consumption figures, a multi-stage design of high costs and weight is needed and it is found, especially with projectile motors, to be advisable to cut down the complexity as much as possible in order to reduce costs, and to lose a little on the efficiency. This also applies to the pumps. Due to the very high speeds at which the pumps operate, cavitation is a serious problem. This is tackled in one of two ways. Either the tanks are slightly pressurised, as mentioned earlier, or a two-stage pump is used, the first-stage being for priming the main stage and giving a few atmospheres pressure only. This is shown on the W.K.9 B pump as used in the H.W.K. 109–509 A.2 which uses screw-type priming stages (Fig. 8). This turbo-pump assembly also illustrates another of the problems arising, that of sealing—certainly not peculiar to rockets but of very great importance. Such oxidants as peroxide and nitric acid can be very dangerous if allowed to leak from the pump, particularly so if it forms a hypergolic mixture with the fuel. The H.W.K. 109–509 A.2 uses hypergolic propellants and the great care taken over the sealing can be seen.

Because of the need for split-second timing in rocket motors, hand controlled valves for starting and stopping are rarely used. Instead solenoid valves are used which control an air supply, which in turn actuates pneumatic valves for starting and stopping the flow of the propellants. Solenoid valves are not normally used by themselves as the high pressures and flows would make them much heavier than the solenoid/pneumatic system. Again, design is along fairly conventional lines, the valves being as light as possible.

5. Testing (Refs. 15, 27.)

Although testing is not usually considered as coming within the scope of design I feel it is justified in this paper for the following reasons. Firstly, even under the best of conditions most rocket motors run with a very small margin between success and failure. The combustion chamber is run continuously at higher temperatures than are found anywhere else in engineering

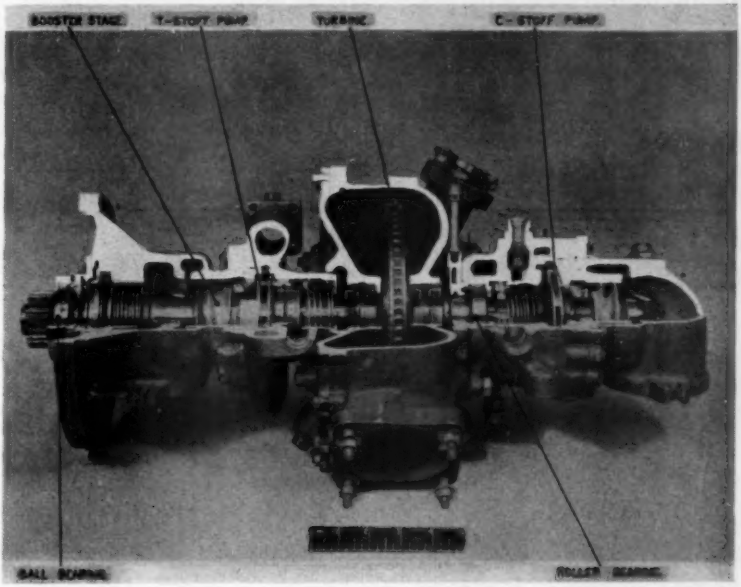


FIG. 8. Walter 109-509 A.2 Turbo-Pump Assembly.

practice and the heat transfer across the walls compared with all other engineering experience is nothing short of fantastic. The chamber and the rest of the motor are stressed as highly as possible. Again, in the present state of knowledge, especially of high-speed heat transfer, the best that can usually be done with slide-rule and drawing board is to produce a rough approximation and perhaps an idea of the relative effects of varying chamber thickness, materials, etc. In order to provide a datum for further work this design must be tested. Further approximations must be designed "on the test-bed" and thus it is that the team of designer-technician-tester should be closer than on any other engine-design work. A competent reciprocating engine or turbine designer has sufficient data on hand to enable him to produce a workable engine off the drawing board. The rocket designer can count himself lucky if his first design for a particular job runs for a few seconds without either blowing up or burning out.

In the first stages of testing, when most trouble is to be expected, the propellant tanks have to be kept well away from the chamber. A typical lay-out for this type of bed is shown in Fig. 9. In general, the control room should be heavily protected by reinforced concrete walls 12 in. or more thick, according to the thrust of the rockets to be tested. The tank bay also should be protected, but the motor bay itself should be of fairly light construction, with at least one end open and an open roof. Weather protection for working, in the form of doors at the ends and a sliding roof is a good investment in our climate.

From the point of view of the operators this is an ideal arrangement but has the disadvantage that in the case of an explosion, fragments can fly for considerable distances. This means that the beds must be built well out in the wilds or a considerable area must be cleared of people before firing. A certain amount of protection can be obtained by covering top and ends with, say, torpedo netting.

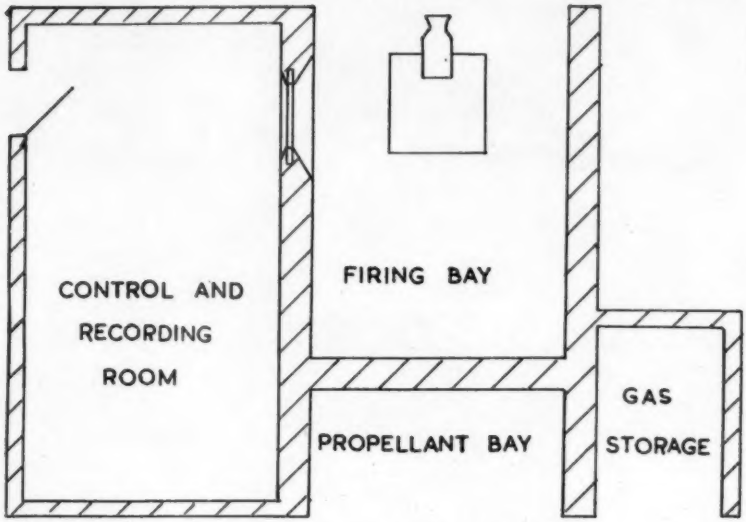


FIG. 9. Typical Test Emplacement.

Alternatively the motor bay can be made strong enough to withstand any explosion which may occur. This latter method, although used in some cases has the drawback that the walls must be made extremely thick in order to cope with the extraordinary effects of blast waves, thus making the structure costly.

One aspect of rocket testing is that of watching the motor during the run. This is most important as it is often possible to see when a motor is not running correctly and to switch off before any damage is done. With experience much can also be determined from the colour, shape and length of the flame. Direct viewing through narrow armour plate glass windows is often used, but to cut down danger from explosions, various indirect methods utilising mirrors or periscopes can be used instead.

As the chamber is the most uncertain of all the rocket components in its behaviour, it is usual to test this separately. A flow test with water is always the first requisite in order to determine the pressure drops in the injector and coolant passage, so that the correct pressure can be applied to give the required flow rates. The number of measurements taken are remarkably few compared with normal engine tests:—thrust, tank pressure, injector pressure, jacket

pressure, chamber pressure and coolant inlet and outlet temperatures are the usual, together with propellant flow rates if these are being measured directly. As rockets are used for such short durations there is no time to jot down measurements and so these must be recorded automatically. A convenient method is to group all the instruments together and use a cine-camera, but this means a delay before the record is available and a further delay before it is analysed. So it is as well, especially when time is at a premium, to have pen-and-ink records in parallel for the more important measurements so that they can be studied immediately after the run. With a new design of chamber it is policy to run it for only a short duration at first, say 5 sec., and then examine it for incipient failure. A lot can deduced from a hot-spot or slight bulge in the chamber. Again, a cine-record of the chamber during the run can be invaluable in deciding the cause of a failure. When the chamber and other components have been developed separately so that they work satisfactorily, they can be assembled and tested as a complete motor.

Conclusions

As it is a fairly new branch of engineering comparatively little exists in the way of design information on rockets. This is particularly true with regard to the heat transfer problems encountered. A peculiarity of the rocket compared with more conventional engines is the very wide choice of propellants available. These are often chosen from the point of view of ease of handling and safety, rather than for their technical advantages. There is plenty of scope for research and development and the next few years should see an increase in performance of perhaps 10–15 per cent. using readily available propellants, and a corresponding decrease in overall weight.

Appendix

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NOTES AND NEWS

Visiting Guests

At a recent meeting of the Society in London we were very pleased to welcome Dr. Johann Goethe, President of the "Süd-Westdeutsche Gesellschaft für Weltraumforschung," who was on a visit to this country. Dr. Goethe had a number of interesting things to say about the revival of astronautics in Germany, in spite of greatly enhanced difficulties. At present Dr. Goethe's group is centred at Frankfurt (am Main), and issues a monthly duplicated information sheet. The group numbers about 50 members, and a number of non-paying associates. Lectures are held regularly.

Professor Hermann Oberth

The Council takes very great pleasure in announcing that Professor Hermann Oberth has accepted an invitation to become the Society's first Honorary Fellow. Professor Oberth will need no introduction to our members, for he is the author of the classic work *Wege zur Raumschiffahrt* and a great pioneer of rocketry. Further details will be given in a later issue.

Morphological Astronomy

Professor Fritz Zwicky, the noted astrophysicist and research director of the Aerojet Engineering Corporation, was recently in England to deliver the 1948 Halley Lecture at Oxford. This lecture has now been printed (*The Observatory*, Aug., 1948, Vol. 68, No. 845, pp. 121–143) and is of very great interest. We have frequently felt that astronomers, as a whole, were too conservative in accepting the possibilities that the rocket has opened up in their science: it is, therefore, a welcome change to find an astronomer making predictions, some of which would stagger the most ardent astronauts!

The "morphological method," according to Zwicky, is simply "an orderly way of looking at things" and so achieving "a systematic perspective over all the possible solutions of a given large-scale problem." It was applied during the War with notable success to the analysis of jet engines and reaction propulsion systems.

Professor Zwicky applies morphological methods to astronomy by considering all the basic elements involved in the problem. They are (*a*) Observation of celestial phenomena, (*b*) Experimentation with celestial phenomena, (*c*) Theoretical integration, (*d*) Use of the knowledge gained, and (*e*) Dissemination of the knowledge and its bearing on all activities of man. As Professor Zwicky points out, (*b*) was never even dreamed of until recently.

Observation of celestial phenomena involves instruments and their location. One of the most promising instrumental developments is the photo-electric telescope, which can amplify faint images and can also *eliminate atmospheric disturbances by using "image stabilisers"* (one of which has now been built by Zworykin).

Further progress depends on locating instruments outside the atmosphere, as may now be done by rockets. Unmanned rockets have grave disadvantages, and "all rocket men are therefore dreaming of vehicles which will carry observers to great heights."

The chief problem of astronomy is the observation of the contents of the universe. So far there has been a good deal of "selection" here, as some objects have been difficult or impossible to observe. New instruments, especially the Schmidt telescope, will help to rectify this state of affairs and give a more objective picture of the universe. Searches are now being made for special objects such as clusters of nebulae, and for supernovae. The latter appear to be caused by nuclear chain reactions which result in single stars shining for some weeks with a brilliance equal to that of an entire galaxy.

The 48 in. Schmidt telescope on Mount Palomar is to be used to test the general theory of relativity by searching for special effects predicted by it.

Gravitational fields focussing light like lenses should be produced by compact nebulae and also by "neutron stars." The latter may exist as remnants of supernovae: they would have a density of some 10^{14} grm./c.c. and they "make possible, in principle, a reversal of time."

Professor Zwicky concludes by discussing some of the rocket projects on which he is engaged. To get instruments clear of all atmospheric effects, heights of 1,000 km. must be reached. "By means of secondary rockets to be launched from primary carriers, this goal should not involve too many difficulties."

Work is also in progress to eject small test particles (mass up to a kilogram) from carrier rockets with speeds greater than the velocity of escape. Hypersonic aerodynamics could thus be studied in the outer regions of the atmosphere. "It is also hoped that the collisions of the test bodies with the Moon and other planetary bodies can be observed and a new method of direct experimentation with these bodies can be established."

In the past, concludes Professor Zwicky,

> "The knowledge gained in astronomy has had wide applications in the conduct of human affairs. . . . An extrapolation of these applications which lies in the line of morphological thinking, and which we might just as well visualise cold-bloodedly, since it appears inevitable, is the *reconstruction of the universe*. The reconstruction of the Earth naturally comes first. One of the biggest problems which comes to mind is the nuclear stabilisation of the Earth. Since no fundamental principle seems to stand in the way of realising nuclear fusion on a large scale, the danger exists that the whole Earth might be exploded by experiments not carefully handled. . . . In the wake of the realisation of large-scale nuclear fusion there will, no doubt, follow plans for making the planetary bodies habitable by changing them intrinsically and by changing their positions relative to the Sun. These thoughts are to-day perhaps nearer to scientific analysis and mastery than were Jules Verne's dreams in his time." A. C. C.

Robert H. Goddard Memorial Professorships

The Daniel and Florence Guggenheim Foundation has given $500,000 to establish facilities for research in Jet Propulsion and Rocket Engineering at Princeton University and the California Institute of Technology. The money is to be used to pay the expenses of Professorships, Fellowships, and similar matters for an initial period of seven years. The principal post in each centre will be the Robert H. Goddard Professorship, named after the famous American research worker. The Goddard Professor at the California Institute of Technology is to be Dr. Hsue-Shen Tsien, formerly Professor of Aerodynamics at Massachusetts Institute of Technology.

B.I.S. Journals and Binders

We understand from the Secretary that the stock of *Journal* binders for Volumes 6 and 7 is now exhausted, and further supplies can only be obtained at a cost of 7s. 6d. each. The stock of Volume 8 binders has been replenished,

however, and can be ordered at any time at the original cost of 5s. 6d. each, post free.

Members might also like to be reminded that extra copies of recent *Journals* can be obtained at 1s. 6d. each, either by post or at meetings.

Of particular interest at present is the fact that a few copies of the September, 1946, *Journal* have become available, at a price of 2s. 7d. each, post free. This number contains a full account of the famous GALCIT experiments, and as it was issued soon after the post-war reorganisation of the Society, only a limited number were printed.

The History of B.I.S. Publications

We have been asked the exact significance of the roman numerals on the front cover of the *Journal*. Of course, the XXVIII on this issue means that it is the twenty-eighth B.I.S. *Journal* to appear—exclusive of all *Bulletins*, Annual Reports and other publications. A brief account of the history of the Society's publications may be of interest, especially to newer members.

The B.I.S. was founded in 1933, and its first *Journal* appeared in January, 1934. To-day, we sometimes regret that our resources do not permit the production of a larger *Journal* than the current bi-monthly one, averaging some 42 pages per number, but perhaps we should take heart from the earlier efforts which appear so very much more modest still by comparison with our current achievement. The whole four issues comprising the first volume (January, April, July and October, 1934) total only 38 pages, and thereafter the *Journal* even failed to maintain its promise of a quarterly publication.

Vol. 2, No. 1, did not appear until May, 1935, and consisted of only a single sheet folded into six pages; there was only one other issue in this Volume (Oct., 1935, 8 pp.), and Vol. 3 likewise consisted of only two numbers (Feb., 1936, 12 pp. and June, 1936, 24 pp.). All this reflected the precarious finances of the Society in its early days, of course; these early issues are also perhaps not notable for any very high scientific standard, but at least we can be proud of the vision and faith in the interplanetary idea which their mere publication implied. An interesting feature of the early *Journals* is the lists of new members —for example, in Vol. 1, No. 4, we find the name of A. C. Clarke, in Vol. 3, No. 1, L. R. Shepherd, while other very early issues mention J. G. Strong, R. C. Abel, M. K. Hanson, and other present members.

Vol. 4, No. 1, appeared in February, 1937, and contained 20 pages; it was the last to be issued from the old Liverpool headquarters. The next number—the tenth to be produced, dated December, 1937—was published early in 1938 from London. It consisted of 24 pages and was edited by E. J. Carnell. (Earlier editors had been P. E. Cleator, the founder of the Society, and L. J. Johnson.) Only two more *Journals* appeared before the War. They were Vol. 5, No. 1, which did not appear until January, 1939, and No. 2 which followed it in July, 1939. Each consisted of 28 pages and was edited by W. F. Temple; these issues were notable for articles describing the "cellular" solid propellant design for a lunar spaceship, evolved by the pre-war Technical Committee.

It may be wondered how interest of members was maintained in these early days when publication of the *Journal* was both irregular and infrequent (only

twelve small issues in six years). None-the-less, membership had risen to over 100 by 1939, and the answer is probably to be found in the less ambitious monthly *Bulletin*, which appeared in addition to the *Journal*, and with the specific intention of providing members with a news-letter on current activities, etc. Initiated in Liverpool, the *Bulletin* was continued by London, and appeared in many forms. Sometimes it was a single duplicated sheet, sometimes a number of such sheets; occasionally it attained the dignity of a cover and, during 1937, for a time it was even set up in proper type. Almost always it achieved a happy informality of style and contained many interesting and amusing items.

In pre-war days, members also received copies of the publications (*The Astronaut*, etc.) issued by the affiliated Manchester Society and, after the War had forced a temporary cessation of B.I.S. activity, some continuity in British publications on astronautics was assured by the appearance of other journals from bodies related (or which later were to become related) to the B.I.S. Thus, Mr. Gatland's A.D.S. produced a journal called *Spacecraft*, while Mr. Burgess's M.A.A. had one with the title *Spacewards*. The latter became the organ of both these societies when they amalgamated into the C.B.A.S. Many issues were produced between 1939 and 1945, and Vol. VI consisted of three printed issues. (Earlier ones had been in duplicated form.)

In 1945, as most members will know, the C.B.A.S. joined with the B.I.S. war-time nucleus to re-form a national society under the old name. The pre-war system of issuing a monthly duplicated *Bulletin* was revived, and the first of the new series, in January, 1946, carried an article by Eric Burgess describing the events leading up to this fusion. This *Bulletin* was the first publication of the re-born Society; the first post-war B.I.S. *Journal* (the thirteenth, Vol. 6, No. 1) appeared as a 32-page issue in June, 1946.

During 1946, eight duplicated Bulletins appeared, then—with the November, 1946, issue—it assumed a bound and printed form similar to the *Journal*. After five issues in this guise, publication of the *Bulletin* was discontinued in May, 1947, as it was considered desirable to concentrate effort on an improved *Journal*, especially since both *Journal* and *Bulletin* had become so similar in appearance and content.

Vol. 6 of the *Journal* consisted of seven issues, appearing once every three months, and totalling 212 pages. With the twentieth issue (Vol. 7, No. 1, Jan., 1948), and after the disappearance of the *Bulletin*, the *Journal* began to come out at its present two-monthly interval, instead of quarterly; the six numbers of Vol. 7 totalled 252 pages. Also since the War, an Annual Report and List of Members has been published for each of the years 1946, 1947 and 1948.

These figures indicate a steady increase in the size of the Society's publications since the War, an improvement which we hope our readers can agree has been matched by a corresponding increase in quality. It is perhaps relevant to point out in conclusion, that contributions and suggestions for the *Journal* are always very welcome, for consideration by the Secretary and the Publications Committee.

THE PLANET MERCURY

By Sheila M. Mather

Mercury, the nearest planet to the Sun, has been known from the earliest times in southern latitudes, though it was there considered to be two separate planets, as it was not realised that the morning and evening appearances were really those of the same object. In the more cloudy skies of the northern hemisphere, the planet has been under steady scientific observation for only the last few hundred years, and even then only for the few hours at sunrise or sunset when it is near its greatest elongation of 28°.

We observe the planet in phases very similar to those shown by the Moon, even to the extent of minor librations, though the full phase occurs when Mercury is on the other side of the Sun, and the Earth, Sun and Mercury are therefore in a near-straight line. At inferior conjunction, *i.e.* when at its nearest to us, we are unfortunately prevented from making any observations at all as the dark side of the planet is presented to the Earth. These difficulties prevent us from obtaining much definite information from practical observations, and we are therefore left with little more than a number of estimates and approximations, about what Professor Lowell so aptly called, "the bleached bones of a world."

Mercury is a small body with a very eccentric orbit, for though its mean distance from the Sun is 36,000,000 miles, at perihelion it approaches to within approximately 28,500,000 miles, while at aphelion its distance is about 43,500,000 miles from the Sun. The mean density of Mercury is 3·8 (that of the Moon is 3·3), and although the lack of a satellite makes the determination of its mass uncertain, the most probable estimate appears to be one twenty-third of that of the Earth.[1] It revolves once in 88 days* which is also the length of its sidereal period or "year," so that the same face and markings are always turned towards the Sun: this will cause the temperature of the dark side to be near absolute zero, while the side turned to the Sun is 770° F., which is certainly hot enough to melt lead or zinc, as there is no atmosphere to carry convection currents round the planet and equalise the temperature.

The lack of any atmosphere on Mercury is to be deduced from (*a*) the small size of the planet, whose low velocity of escape of 2·3 m.p.s. would allow the molecules of any atmosphere there might have been to escape into space, especially since such molecules would be in a state of exaggerated motion, due to the great heat from the Sun, to which the little planet is so close; (*b*) the low albedo; and (*c*) the fact that there is no prolongation of the "horns" during the crescent phase, as there is with any planet possessing an atmospheric envelope, such as Venus. Despite all this apparent evidence to the contrary, however, both Schiaparelli and Antoniadi have said that they have seen white cloud-like objects obscuring certain portions of the planet's surface from time to time.

* This is the usual estimate, originally put forward by Schiaparelli but still unconfirmed, which has led Spencer Jones to say that Mercury's rotation period is still an open question, as measurements taken at Mount Wilson of radiation from both the dark and sun-lit faces of the planet seem to point to a much shorter period of rotation. Such a period (24 hrs. 5 mins.) was suggested by Schröter in the 19th century.

These may, however, have been subjective, rather than atmospheric phenomena, although Antoniadi held firmly to the belief that Mercury possessed a thin but dust-infested atmosphere, and it was stated by Flammarion that certain regions were held by many to be the sites of seas or oceans.

Schiaparelli and Antoniadi have also described definite and permanent markings that they have seen on the visible face of the planet, and their respective maps show a remarkable similarity in the main features for work done by two different observers, although later opinions, including that of the Astronomer Royal, Sir Harold Spencer Jones, incline to the view that the permanency of such markings is extremely doubtful.[2]

Mercury seems to be, in many respects, almost the twin of our own Moon. Not only are they similar in density, but also in the colour and polarisation of their reflected light, which seems to indicate that their respective surfaces may resemble each other in being rough and ash-covered.[3] It is possible also that the internal structures of the two small bodies may be the same, and a theory has been postulated that Mercury may have been at one time a satellite of Venus, possibly torn from her by the greater gravitational attraction of the Sun, which would account for the incidence of a planet of such small density in a situation where one might expect to find one of much greater density, according to Jeans' theory of the origin of the Solar System. Against this conjecture are the comparative sizes of Venus and Mercury—the former being 7,700 miles in diameter to the latter's 3,100 (compare the Earth's 7,913 and the Moon's 2,160)—satellites being generally considerably smaller in proportion to their primaries.

Altogether, if our deductions are correct, Mercury seems to be a most inhospitable little world, but perhaps the extreme conditions prevailing there may be less drastic at the terminator, especially if the estimate of 88 days for the rotation period is proved to be the right one, so that future explorers may find in the "twilight belt" where the two extremes of heat and cold, light and dark converge, the most suitable location for their landing. Until then we must wait for final proof as to whether Mercury is a barren, airless waste, a dying planet with thin and dust-befouled atmosphere rapidly whirling away molecule by molecule into space, or a living world populated by life-forms alien to any we can imagine, snatching a rich living from the appalling conditions they know as normality.

REFERENCES

(1) Sir H. Spencer Jones, *General Astronomy*.
(2) ,, ,, ,, ,,
(3) F. Whipple, *Earth, Moon and Planets*.

NOSE DRIVE OR TAIL DRIVE?

We have frequently been asked whether nose-drive rockets are inherently more stable than ones with tail drive. This is a constantly recurring fallacy which often finds its way into print, and which is based on the misconception of comparing the forces acting on a rocket with those involved, *e.g.* in raising (or lowering) a pencil.

In the case of the pencil, the supporting force (T) remains vertical, like the weight (W), and does not pass through the centre of gravity (C.G.). Thus, when the pencil is pushed from below (Fig. 1 (*a*)) the result is unstable, whereas if it is pulled from above, the opposite is true, since then the moment present tends to restore the pencil to the desired vertical position (Fig. 1 (*b*)).

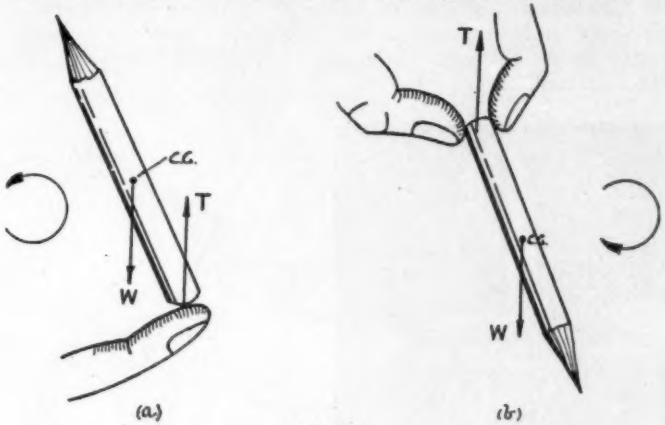

FIG. 1.

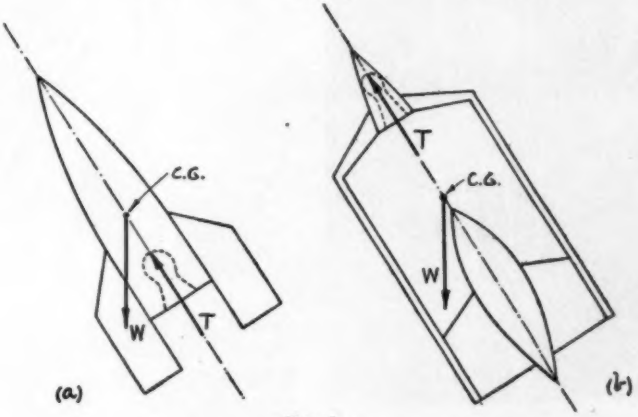

FIG. 2.

For the rocket, however, the comparable force (T) always tilts with the axis of the rocket itself, and always passes through the C.G., about which the rocket will rotate when disturbed from its vertical position. Thus, there is no difference whatsoever between the two cases of tail-drive (Fig. 2 (*a*)) and nose-drive (Fig. 2 (*b*)). Neither has any inherent stability, and each must therefore be controlled by other means.

Of course, the same argument applies whether the rocket is ascending ($T > W$) or descending ($T < W$) under power. It should be made clear, however, that the reasoning is of course limited to cases where the rocket motor is conventionally mounted, fixed relative to the rocket axis. If the motor is free to pivot, on some sort of universal mounting, then the force (T) can be maintained parallel to W, and so the configuration of forces applying for the pencil *can* be realised. In that way, a nose-drive rocket *could* be made inherently stable, but such a refinement is not usually envisaged when the question is asked.

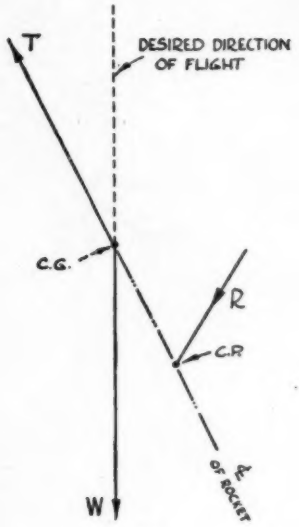

FIG. 3.

FIG. 4 (side). A "Repulsor" nose-drive rocket built by the VfR.

The above discussion does not include consideration of aerodynamic forces, which are very important for small rockets, but much less so for large ones. It is, of course, usual to ensure some measure of automatic stability for rockets by providing them with fins at the rear. These fins introduce an aerodynamic restoring force (R), which acts through a centre of pressure (C.P.) behind the C.G. (See Fig. 3.) Now, with a nose-drive layout, the C.P. almost inevitably

tends to come out further behind the C.G. than for a tail-drive. The actual shape of the rocket itself provides a large effective fin area; for the same degree of aerodynamic stability, smaller real fins would be needed, but if fins of equal size are fitted, then the aerodynamic stability is greater. This fact undoubtedly was responsible for the better flight characteristics claimed for nose-drive rockets built by the early German and American experimenters—for example the VfR "Repulsors," such as the one shown in Fig. 4. A secondary effect may have confused the designers into the belief that some more fundamental principle was at work; at least, this confusion has been passed on to many of those taking a subsequent interest in the subject.—A. V. C.

KNOW YOUR COUNCIL

H. E. ROSS, born 1904; educated at Mansfield Road School, London N.W.5,. On leaving school, became a laboratory assistant in the Prosectorium of the London Zoo. Mr. Ross tells us that the high-lights of this occupation included pulling the lions' tails, birds'-nesting round the Mappin Terraces, finding a live python on the roof of the Reptile House, and learning to shoot with a ·45 Webley. In his spare time he also learned how to make microscope slides and became adept at skinning anything from humming-birds to tigers. Later Mr. Ross went to the London School of Tropical Medicine and Hygiene, where, in the Department of Helminthology, he worked under the direction of Professor Leiper.

During 1920–21, Mr. Ross studied radio and obtained a P.M.G. certificate. In 1924 he entered the Marconi International Marine Communication Co. as an operator and went to sea, sailing to South Africa, Ceylon, India, and South America. High-lights of this period—sight of the Peak of Teneriffe at dawn; nearly being shipwrecked in Colombo Harbour whilst out sailing in one of the ship's boats; smoking Mandalay cheroots at a halfpenny a time and wearing a solar topee. Low-lights—feeling like Dr. Livingstone in Calcutta and trying to enjoy eating *chili con carne* whilst expecting to be liquidated in a low dive in Buenos Aires.

Forsaking the sea for the even more precarious existence of factory life, Mr. Ross worked for a time in the Radio Inspection Department of the New Southgate (London) works of the Western Electric Company (now Standard Telephones and Cables). From thence Mr. Ross obtained an appointment with Messrs. A. C. Cossor, initially as Technical Assistant and later taking over charge of the manufacture of all "Mains" type radio valves. In 1941 Mr. Ross went to High Wycombe (Bucks.) to initiate the training of labour for a shadow factory operating under the management of A. C. Cossor Ltd. He is at present Production Control Superintendent at this factory, which is now operated by Messrs. Electronic Tubes Ltd., and is also a member of the Electric Lamp and Radio Valve Manufacturers' Technical Committee.

Mr. Ross joined the B.I.S. very shortly after the Headquarters moved from Liverpool to London in 1937, and has remained an enthusiastic and staunch supporter of Astronautics ever since. He was a member of the pre-war Technical Committee, participated in the 1945 re-birth and amalgamation, and is a Fellow and Council Member of the Society.

In co-operation with Mr. R. A. Smith, Mr. Ross has written a book on Astronautics. However, Mr. Ross tells us that "as it runs out to a total of one word for every mile to the Moon, there is probably not enough paper in the Universe to get it published at the present time."

His fondest hope is that those who cross space will be imbued with an ethical and philosophical code commensurate in quality with the magnitude of their solar voyagings.

RALPH ANDREW SMITH. Born 1905; educated at St. Peter's Eaton Square Choir School and Ealing County. Matriculated in 1921. Became interested in space-flight at the tender age of 12, and has remained an enthusiastic advocate of its possibility ever since.

On leaving school, he commenced training as an aircraft engineer and served an abortive apprenticeship with a firm, which in those difficult years immediately after the first war, found itself obliged to abandon its aircraft activities in favour of making money. Though forced by circumstances to follow the same lines, he retained interest in science and aeronautics, and maintained contact with engineering by securing commissions as a free-lance draughtsman and design consultant, while making sufficient money to keep alive, in the very much better paid spheres of architectural decoration and furniture design.

During this period he took part in the early development of television, becoming a director of British Kinephone Ltd. and acquiring experience of the design of cinema sound equipment, television, and radio production engineering. He joined Cossors at the outbreak of war in the drawing office of the Radar production factory, and was responsible for the layout of two new "shadow factories." Subsequently, Mr. Smith was transferred to one of them, at High Wycombe, where he specialised in the design of machines for television tube and radio valve production, jigs, tools and plant maintenance. He is now a designer-draughtsman at the M.O.S. Rocket Propulsion Research Establishment, dealing with the development of rocket power plants and associated equipment.

Joining the Society when headquarters moved to London in 1937, he was Organising Secretary and a member of the Technical Committee until the outbreak of war forced the Society into temporary suspension. During the war he was one of the nucleus who maintained contact, and took an active part in the post-war fusion of the C.B.A.S. and B.I.S. He was one of the ten original Guarantors of the Society and has served on the Council since its inception.

"Smithy" is well known to the members for his many contributions to the *Journal* and to lecture discussions; he thoroughly enjoys keen debate and insists on a fair hearing of the other point of view . . . even when it happens to be his own.

ABSTRACTS

EDITED BY J. HUMPHRIES

Telemetering Guided-Missile Performance

(J. C. Coe. *Inst. Radio Engrs., Waves & Electrons Sect.*, Vol. 36, No. 11, pp. 1404–1414, illus., refs.)

A discussion of the requirements of telemetering systems and their airborne and ground installations, with details of antenna and transmitter installations, transducer designs, and frequency-modulated multiple-subcarrier and pulse-position systems used at the U.S. Naval Aircraft Missiles Test Centre. (Abs. from *Aeronautical Engng. Rev.*, Feb., 1949, Vol. 8, No. 2, pp. 55–56.)

The Cosmic-Ray Intensity above the Atmosphere

(A. V. Gangnes, J. F. Jenkins, jun. and J. A. Van Allen. *Phys. Rev.*, Jan. 1, 1949, Vol. 75, No. 1, pp. 57–69, illus., tabs., refs.)

In a series of flights of Aerobee and V.2 rockets at geomagnetic latitude $\lambda = 41°$ N., single Geiger counters and Geiger counter telescopes have been employed to measure the total intensity of cosmic rays above the appreciable

atmosphere. The directional intensity j, averaged over the upper hemisphere, is found to be $0{\cdot}120 \pm 0{\cdot}009$/sec./cm.^{2}/steradian, constant from 55 km. altitude to the highest altitude reached of 161 km. This result is an experimental upper limit to the primary intensity of charged particles at this latitude.

Chemical Reaction during Adiabatic Flow through a Rocket Nozzle

(D. Altman and S. S. Penner. *J. Chem. Phys.*, Jan., 1949, Vol. 17, No. 1, pp. 56–61, illus., tabs., refs.)

An analysis has been carried out for isentropic expansion through a representative rocket nozzle. The rate of change of temperature of an element of gas with distance and time in the vicinity of the nozzle throat is discussed in some detail. By use of Daniels' rate constant for the formation of nitric oxide from nitrogen and oxygen, it is shown that the temperature changes so rapidly that the reaction $2NO \rightleftharpoons O_2 + N_2$ produces insignificantly small composition changes below about 2800° K. when the temperature in the rocket chamber is 3000° K.

Corrosion of Metals in Red Fuming Nitric Acid and in Mixed Acid

(N. Kaplan and R. J. Andrus. *Ind. & Eng. Chem.*, Oct., 1948, Vol. 40, No. 10, pp. 1946–7, tabs., refs.)

Both red fuming nitric acid and mixed acid are widely used as oxidants in liquid-propellant rocket motors. In this investigation several stainless steels and Duriron exhibited good resistance to corrosion by concentrated nitric acids, aluminium alloys were more extensively attacked, Haynes-Stellite alloys and chromium were only slightly corroded, and tin, gold and tantalum exhibited very good resistance to corrosion, even at elevated temperatures. Corrosion rates in mixed acid were lower than in the other nitric acids for most of the metals tested.

Hydrogen Peroxide as a Source of Power

(R. Simard. *Engng. Jnl.*, April, 1948, Vol. 31, No. 4, pp. 219–225.)

A comprehensive review of German work at Walter's. Description of production plant, properties, uses and methods of handling. Lists weapons in production during the war or under test using 80 per cent. hydrogen peroxide, and summarises also other projected war and peace-time uses.

THE BRITISH ASTRONOMICAL ASSOCIATION

Founded 1890, now numbers 2,000 members. Open to all interested in Astronomy. Chief objects are the association of observers for mutual help, circulation of astronomical information, and encouragement of popular interest in Astronomy. The Association issues a *Journal* about nine times annually, *Circulars* giving current Astronomical news, and *Memoirs* on the work of Sections, including the Sun, Planets, Comets, Auroræ, and Variable Star Sections.

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Applications of the Theory of Free Molecule Flow to Aeronautics

(H. Ashley. *J. Aero. Sci.*, Feb., 1949, Vol. 16, No. 2, pp. 95–104, graphs, tabs., refs.)

The breakdown of certain assumptions of conventional aerodynamics in the case of highly rarefied gas is shown to call for the use of the theory of free molecule flow in studying forces on bodies moving about 120–150 km. in the earth's atmosphere. A tentative standard table of atmospheric properties from 120–220 km. is computed. The parameter $M\infty$, ratio of flight speed to most probable speed of air molecules, becomes useful in comparing free molecule flows. Techniques are developed for finding analytically or numerically the lift and drag coefficients of any object, based on two extreme opposite assumptions concerning the nature of reflection of molecules from surfaces. These methods are employed to find coefficients of a number of simple bodies. The drag of missiles is demonstrated to be negligibly small above 120 km. except at extremely high speeds. The possibility of aerodynamically sustained flight is discussed.

Moon Echoes and Penetration of the Ionosphere

(E. J. Kerr, C. A. Shair and C. S. Higgins. *Nature*, Feb. 26, 1949, Vol. 163, No. 4139, pp. 310–313, illus., tabs., refs.)

Using 20 Mcs. transmission, echoes from the Moon have been obtained on 13 out of 15 attempts. The amplitude of the echoes was sometimes of the order expected on theoretical grounds, but more commonly it was considerably less. As the Moon rose, echoes could not be obtained until the Moon's angle of elevation was higher than was expected from calculations based on vertical-incidence ionospheric soundings. Analysis of 20 Mcs. solar noise also shows ionospheric effects, with the significant difference that solar noise energy has been received at lower elevations of the sun than expected.

Detection of Radio Signals Reflected from the Moon

(J. H. De Witt and E. K. Stodola. *Proc. I.R.E.*, **37**, 229–242, Mar., 1949.)

A paper describing the experiments at the Evans Signal Laboratory, Belmar, N.J., which resulted in the reception of radio signals from the Moon has just been published in the *Proceedings of the Institute of Radio Engineers*.

The theory of lunar radio echoes is developed mathematically: owing to the fact that the Moon is a very rough, extended body, returning echoes may be received from the entire hemisphere facing the Earth, and spread over a time interval of ·0116 sec. This makes desirable the use of a long transmitter pulse: in the Signal Corps experiments a pulse width of ·05 sec. was used. Signals were sent out at 4 sec. intervals, to give ample time for the echo to return (the time-lag for the complete journey being 2·5 sec.).

The first echoes were received at moonrise on January 10, 1946, and many interesting experimental results have since been obtained. Large and rapid variations in the received echo have been observed: it may be very strong at one moment, and almost undetectable 4 sec. later. At other times no echoes can be received at all.

Apart from their astronomical importance, these experiments are of some practical interest in view of the possibility of using the moon as a passive reflector of short-wave signals. However, the difficulties are very great in view of the losses on the round trip, although the authors remark: "if it ever becomes practicable to put a non-passive relay station on the Moon, possibly with means for regenerating the signal shapes, earth-point to earth-point communication via the Moon might look much less discouraging."

The results of this experiment are also employed to discuss briefly the powers needed for one-way communication. It is decided that even without elaborate aerial systems a 1 kw. F.M. station could be received on the Moon, and that "using only presently developed radio equipment, Mars and Venus are also at times within reach of a 50 kw. F.M. station on the Earth, and vice versa."

Heat Transfer in Sweat-Cooled Porous Metals

(S. Weinbaum and H. L. Wheeler, jun. *J. App. Phys.*, Jan., 1949, Vol. 20, No. 1, pp. 113–122, illus., refs.)

Sweat-cooling is one of the most promising methods yet envisaged for cooling high-performance rocket motors. In this theoretical article the heat transfer inside sweat-cooled metals is analysed and formulas showing the temperature distributions along the length of a sweat-cooled bar and across a sweat-cooled hollow cylinder are derived.

Fire for the Wars of China

(T. L. Davis. *Ordnance*, July–Aug., 1948, Vol. 33, No. 169, pp. 52–3, illus.)

Evidence on the early military history of rockets in China, obtained from the *Wu pei chih* (*Treatise on Military Equipment*) by Mao Yuän-i, written about 1621, is discussed. Various types of fire-arrows, rockets and launchers are described and the author concludes that it has not been proved that rockets were used for military purposes in 1232, as is generally supposed.

Tracking the Rockets

(M. Mann. *Ordnance*, July–Aug., 1948, Vol. 33, No. 169, pp. 23–5, illus.)

Brief descriptions of the various devices used, in particular, the Mark IV Tracking Telescope, a 16-in. astronomical telescope fitted with a 35 mm. cine-camera, mounted on a 90-mm. anti-aircraft gun, used for following V.2 flights at White Sands. Other optical systems are mentioned and the radar Doppler system explained.

Experimental Study of Cooling by Injection of a Fluid Through a Porous Material

(P. Duvez and H. L. Wheeler, jun. *J. Aero. Sci.*, Sept., 1948, Vol. 15, No. 9, pp. 509–21, illus., tabs., refs.)

A method of coping with the high rates of heat transfer in the field of jet propulsion consists of making the parts to be cooled of a porous material and forcing the cooling fluid through the pores in a direction opposite to that of the

heat flow. This method is referred to as "sweat-cooling." The study of sweat-cooling heat transfer discussed in this paper has the limited objective of defining the variable involved in the problem and of establishing the experimental techniques. A full description of these techniques is given. Extensive tables and graphs of the data obtained are also given. This experimental study of sweat-cooling has shown that either a liquid or a gas may be used efficiently as a cooling fluid. A theoretical expression is derived relating the surface temperature of the porous material, the weight flow rate of the coolant, and the temperature and weight flow rate of the main stream of hot gas. The validity of this expression is discussed on the basis of the experimental data that have been obtained.

Full-scale Free-flight Ballistic Measurements of Guided Missiles

(L. A. Delsasso, L. G. de Bey, and D. Reuyl. *J. Aero. Sci.*, Oct., 1948, Vol. 15, No. 10, pp. 605–15, illus., refs.)

Special problems arising in the instrumentation of full-scale free-flight tests are considered, particularly as pertaining to guided missiles. Applications of specialized optical and electronic equipment are reviewed in detail.

Under optical instrumentation, such problems as the modification and application of acceleration cameras, phototheodolites, and precision-plate cameras are discussed. In addition, the development of tracking telescopes using refractors and reflectors of large effective focal length in conjunction with special mounts for studying the behaviour of missiles during the entire flight is considered; results obtained so far from these instruments are included. Brief reference is made to the methods for determining ballistic data, by means of high-speed motion-picture cameras, for aircraft rockets launched from airplanes.

Under electronic instrumentation, the use of radar for trajectory determinations and the modifications necessary on standard radar equipment for use in long-range guided missiles are discussed. The use of radio-doppler and the application to this field are considered in detail, and the problems and advantages encountered in this field are presented. The usefulness of microwave reflection doppler equipment is also reviewed. Finally, a comparison of the results obtained by the various systems of instrumentation is made.

Other Papers Noted

V-2 Cloud-Chamber Observation of a Multiply Charged Primary Cosmic Ray. S. E. Golian, C. Y. Johnson, E. H. Krause, M. L. Kuder, G. J. Perlow and C. A. Schroeder. *Phys. Rev.*, Feb. 1, 1949, Vol. 75, No. 3, pp. 524–525, illus., refs.

Missiles Enter Production Stage. *Aviation Week*, Feb. 7, 1949, Vol. 50, No. 6, p. 15, illus. Notes on Convair 774 and North American NATIV.

Rotochute for Supersonic Missiles. F. Coleman. *American Helicopter.* Brief description of rotating-wing device developed by G.E.C. for lowering instruments and air samples from high-altitude sounding rockets.

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Energieprobleme des Weltraumschiffs. Heinz Gartmann, *Die Umschau in Wissenschaft und Technik*, Feb. 15, 1949, pp. 99–102. A short summary of the energy problems of space-flight, with several tables and illustrations.

Calculation of Rockets. G. Azzioni, *Revista Marittima, Technical Supplement*, July, 1948, pp. 169–196, 8 illus. (In Italian.) Extended English summary appears in *Engineer's Digest*, Feb., 1949, 10 (2), 36–40.

Rocket Motors—Practical Design Problems and their Solution. G. P. Sutton, *Machine Design*, Dec., 1948, 20 (12), 101–105. A brief description of the liquid-cooled rocket motor followed by a discussion of manufacturing techniques and difficulties caused by the high operating temperature of the motor, *e.g.* thermal expansion, weakening of chamber walls, thermal stresses. Selection of wall material is also dealt with.

Materials for Bi-Fuel Rockets. R. M. Chapman. *B.I.O.S.*, Item No. 4, Final Rept. 556, H.M.S.O., December, 1947, 20 pp. A description of the materials used by Walters for C-stoff and T-stoff. Deals with special steels, aluminium and its alloys, synthetic materials, paints and varnishes. Specific components such as tanks and pipes are dealt with and there are two appendices dealing with the surface treatment of metals.

Bayerische Motor Werke (B.M.W.). H. A. Liebhafsky, R. H. Norris and E. H. Hull. *C.I.O.S.*, Item No. 5, File XXVI–83, H.M.S.O., 1947, 10 pp., illus. A brief account of the test-beds and facilities for testing nitric-acid rocket motors.

Patent Application on Improved Combustion for Rocket Engines. W. Schmidding. *U.S. Air Force Trans.*, No. F–TS–2832–RE, 26th Feb., 1947, 2 pp.

The Guided Missile. C. F. Green. *Ordnance*, Sept.–Oct., 1948, Vol. 33, No. 170, Sect. 1, pp. 96–8, illus.

REVIEWS

The Science and Engineering of Nuclear Power—Vol. I

(Edited by Clark Goodman and published by Addison-Wesley Press, Inc., Cambridge 42, Mass., U.S.A., 501 pp., index, graphs.)

This work is the first of two volumes, written by a number of specialists in the field of atomic energy and nuclear physics, and based upon a course of lectures which was started in 1946 at the Massachusetts Institute of Technology. It is intended primarily for scientists and engineers working in the field of

nuclear energy, who may not have had any previous special training in nuclear physics.

The work is mainly an account of the Neutron Diffusion Theory and its application in the design and operation of piles and other thermal reactors. Two introductory chapters give a fairly comprehensive account of the aspects of nuclear physics which are relevant to the application of nuclear power. Brief attention is given to the physics and chemistry of nuclear fuels and their fission products and some space is devoted to a discussion of the preparation of uranium from its ores and to the separation of the fissile isotopes. Finally, there is an account of some of the engineering aspects of the design of reactors, particularly the problem of heat transfer. The text includes many useful tables of nuclear and other important constants and concludes with a large number of charts of nuclear cross sections of the natural elements.

This work has some shortcomings, but by far the most serious is its complete dependence on declassified material. This naturally prevents the authors from dealing with the subject in the most comprehensive manner and forces them to rely on pre-war data on such things as the nuclear cross sections of the uranium isotopes. Nevertheless, it is a most valuable book for scientists and engineers working in the field of atomic energy, and can be recommended to all those interested in the subject. L. R. S.

Principles and Methods of Telemetering

(By Perry A. Borden and Gustave M. Thynell. Pp. 230, 106 figs. Reinhold Publishing Corp., New York. 1948. Obtainable from Chapman and Hall, Essex Street, London. Price 27s.)

This book gives an account of the principles of telemetering, with detailed descriptions of the various systems in use in the United States. Instruments employing change of current, voltage or frequency for remote registration are first described, followed by a discussion of d.c. and a.c. methods of telemetering position (*e.g.* by "Selsyns"), numerous pulse and carrier-current systems are described, as well as methods of interconnection which enable several channels to operate simultaneously on the same circuit. Instruments for totalising, computing and integrating are briefly considered, as well as remote-reading dials and registers.

Methods of radio-telemetering are not specifically dealt with, the treatment being confined almost entirely to wired circuits.

The book concludes with a list of 79 references and some 300 patents.

A. C. C.

Neutron Effects on Animals

(Edited by Ellice McDonald. 198 pp., 71 figs. and 32 tables, 16s. 6d. net. Williams & Wilkins Company. Obtainable in England from Baillière, Tindall & Cox, 7–8, Henrietta Street, W.C.2.)

This is a joint work compiled by the staff of the Biochemical Research Foundation of Newark, Delaware, under the direction of Ellice McDonald. It is an account of studies carried out over a period of years on the effects produced by fast neutron irradiation of various animals.

The text is concerned almost entirely with experiments carried out at the Biochemical Research Foundation. In all the investigations, the neutron source was a beryllium target bombarded by deuterons in a cyclotron. The neutrons produced in this way had energies up to 13·5 million electron volts. The irradiated animals were placed in cages in various regions of the cyclotron room, and neutron dosages measured by means of Victoreen 100 *r* chambers, and are given throughout the text in terms of "*n*-units." The "*n*-unit" is the quantity of neutron radiation which produces the same effect in the Victoreen chamber as one Roentgen of X-rays. The adoption of such an arbitrary unit is one of the main shortcomings of the work described.

There is a short account in this book on the gross pathology, nematology, and mortality of white rats and dogs irradiated by neutrons. Some attention is also given to the effect of such radiation on micro-organisms and upon plant material. The greater part of the work, however, is devoted to the chemical effects produced in the irradiated animals, but in this the book is rather a series of research reports than a comprehensive survey of the subject. It is emphasised that the research undertaken is of an exploratory nature, seeking the most promising lines of future research. Despite the preliminary character of the work, however, many interesting facts are recorded. An introductory chapter by Ellice McDonald is devoted to a general discussion of the mechanism of irradiation effects. It is noted that the most lethal radiation for cell destruction is ultra-violet light of wave-length 2536Å. It is possible that the production of a secondary radiation of this wave-length by the primary neutrons or X-radiation may be the mechanism whereby the cell destruction is brought about, though there is little evidence to support this. L. R. S.

CORRESPONDENCE

Man and his Mark

SIR,

In the course of a lecture, entitled "The Morphology of Astronomy," Professor Zwicky, of the California Institute of Technology, stated that he visualised the possibility of a missile being discharged so that it came into contact with the surface of the Moon, thus affording visible proof of the possibility of directing a body there under control from the Earth.

This suggestion has been advanced on other occasions, notably by Professor Goddard, coupled with the suggestion that the missile should be so charged with explosive that contact with the Lunar surface caused a flash which could be observed from Earth.

As there now appears to be some possibility that an attempt will actually be made to achieve this purpose I wish to place on record a protest against what I regard as a piece of scientific hooliganism. In the first place I consider that the information gained would be of little scientific value, and the possibility of damage to the surface of the satellite considerable. What is more, there is little doubt that if one group of experimenters were successful in achieving their aim, this would then become the immediate purpose of all other groups, who

were technically equipped to emulate, or exceed it. Successive and progressively more violent explosions would become the hobby of every group of scientific louts who were desirous of impressing others with their technical powers.

In the course of this gratuitous and pointless destruction, some of the natural features of the Moon would be interfered with and possibly something unique in the universe might be shattered.

The surface of the Moon is most probably mechanically unstable to a great extent, because of the low gravitation, high slip angle, lack of eroding forces and sedimentary reinforcement of the rock masses extruded from the interior.

Although I am inclined to the view that there is no life on the Moon, I cannot consider that view as being anything more than a hypothesis of probability. We do not know. If there were any activity parallel to life as manifested on Earth, one must acknowledge the high degree of probability that its mechanism must differ radically from any form with which we are familiar. So much so, in fact, that it is extremely unlikely that we should recognise it for what it is by telescopic examination of the surface. Although the Moon lacks free oxygen in the gaseous state, we have no reason to suppose it lacks it altogether. In any case there is an abundance of available energy in the sunlight to provide a possible vitalising motive. Should mankind be permitted to herald his coming in the wider universe with pointless destruction?

I would suggest that it would be far better an aim to place a vehicle equipped with television in an orbit around the Moon, and thus conduct a close range survey of its characteristic structure. It should then become possible to land a test body on some selected surface, carefully chosen as being devoid of unique features, so that the possibility of irreparable damage is restricted.

I would like to point out to the American Government and all other governments, that the Moon is not their property, and will not become so by right of bombardment. It is the common heritage of man, possibly, if otherwise untenanted, and although there is little we can do at the present to prevent the Americans or others from abusing their present position of technical advantage, they would be stupid to overlook the possibility that militaristic exhibitionism normally evokes unpleasant reactions—ultimately.

R. A. SMITH.

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